Figure 35 is a graphical representation of variation of EFL in two buffer tubes, where on tube has a rigid reel core and constant take-up tension, while the other has a thin foam layer on the core and decaying take-up tension;

Figure 36 is a graphical representation of linear speed of a tube as a function of time;

Figure 37 is a graphical representation of three different EFL distributions as a function of length of the buffer tube and variations in angular speeds;

Figure 38 is a diagrammatical representation of a buffer tube manufacturing system according to one embodiment of the present invention;

Figure 39 is a graphical representation of EFL in two buffer tube samples after loading with a parabolically decaying take-up load;

Figure 40 is a diagrammatical representation of a pad or stiffness member being inserted into a buffer tube winding according to one embodiment of the present invention; and

Figure 41 is a diagrammatical representation of an apparatus to be used to perform the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will be explained in further detail by making reference to the accompanying drawings, which do not limit the scope of the invention in any way.

In the development of the present invention, a significant amount of testing and experimentation was conducted. The goal of this research was to better understand the cause of the EFL parabola, and to find a means to control and flatten the EFL parabola through a "smart process". As a final goal, the EFL distribution along the length of buffer tube should be a small constant, preferably from approximately 0.05% to 0.15%.

In order to achieve the main research goal, it was necessary to model the winding process for buffer tubes (see Figure 3 showing a buffer tube 30 under tensile force "T" reeled on a spool "S" that rotates at angular velocity "ω") and to analyze the stress distribution as a function of geometrical, process and material parameters. This was done using two main analytical tools, the first being analytical closed form solutions and the second being finite elements analysis, the results of which were then compared to experimental results. The goal of the analytical closed-form solutions was to obtain equations relating the variation in the EFL, strain and stress to the core radius, maximum radius of the roll, material properties and take-up tension. The goal of the finite element modeling was to better understand the influence of material parameters and the transient dynamic process (continual adding of stressed material to an already stressed deformed body), and to consider instability of motion and sliding of layers with friction.

The desired outcome was to find a method and apparatus which allowed the manufacture of buffer tubes with relatively small EFL variation throughout the length. Such a distribution is shown in Figure 2, where the distribution 2 is a substantially even EFL distribution, throughout the length, achieved by the present invention.

Based on preliminary analysis, it was suggested that the parabolic distribution of EFL was a result of the parabolic distribution in circumferential stress. Consequently, the solution to the problem of straightening the EFL parabola was determined to include straightening the circumferential stress curve.

In order to verify these assumptions, the research program included simplified analytical solutions, refined finite element models, and experiments to analyze the process of winding of buffer tubes. The contribution of major factors to the distribution of stresses in

the wound material was analyzed. The first analytical model considered was a thick-walled cylinder under tensile stress. The second analytical model was based on the model of a shrunk ring; this model additionally took into consideration the difference between the stiffness of the wrapped material and that of the reel core. Also, the second analytical model allowed for the consideration of a variable winding tension, which according to the present invention, is one method used to create a substantially uniform EFL distribution.

The buffer tube roll geometry was characterized by initial radius, i.e. radius of the reel core, and the maximum radius of the roll. The maximum radius was expressed in terms of the number of wraps and thickness of the material (such as thickness of a tape or outer diameter of a buffer tube). The take-up tension was represented by a wrapping stress, which may or may not vary during the winding process. Considering the equations of equilibrium in terms of stresses provided a short and simple way to compute the stress distribution in the wound roll.

In order to compute the distribution of strains in the roll, additional equations relating stresses and strains through material properties were considered. The stresses and strains were related to each other through the equations of plane stress or plane strain.

In the computation of EFL, it was assumed that the fabrication process resulted in a close to constant value of EFL_0 (which is the EFL of the tube after the tube is manufactured but prior to the tube being reeled). This value, however, undergoes changes because of a non-uniform stress field in the structure on the reel. The optimization goal is to minimize the range of variation of EFL in the roll and to adjust the level of EFL to a small positive value, preferably about 0.10 ± 0.05%.